Chiral Quirkonium Decays

Ricky Fok
University of Oregon/Fermilab

SUSY 2011
08/30/2011

R. Fok, G. Kribs
Phys. Rev. D 84, 035001 (2011)

What are quirks?

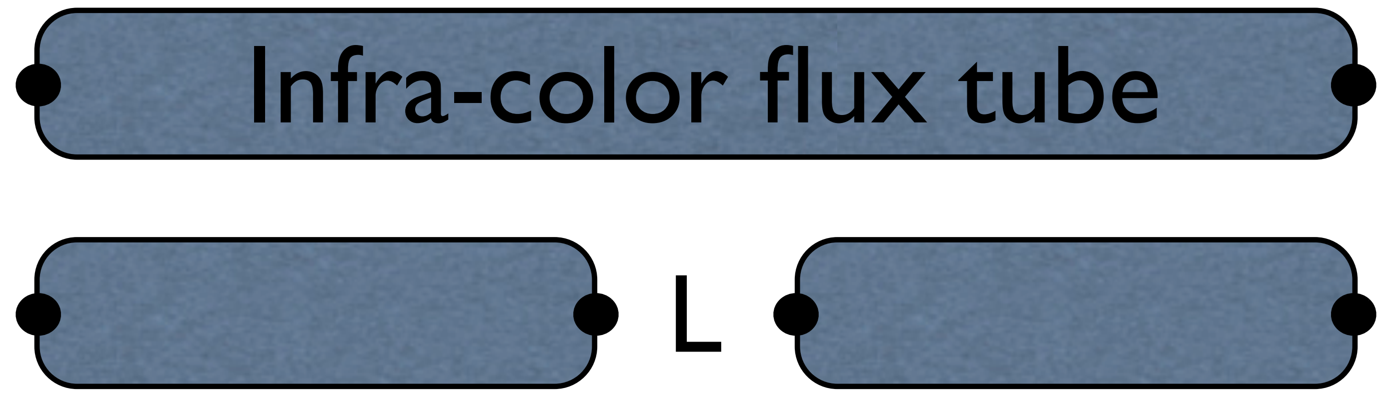
J. Kang and M. A. Luty,
JHEP 0911, 065 (2009)

"Quarks" confined under *infra-color*

$$m_Q >> \Lambda_{IC}$$

No fragmantation! Why?

Flux tube energy over length L, $> 2m_Q$



$$\boxed{\Lambda_{IC}^2 L > 2m_Q}$$

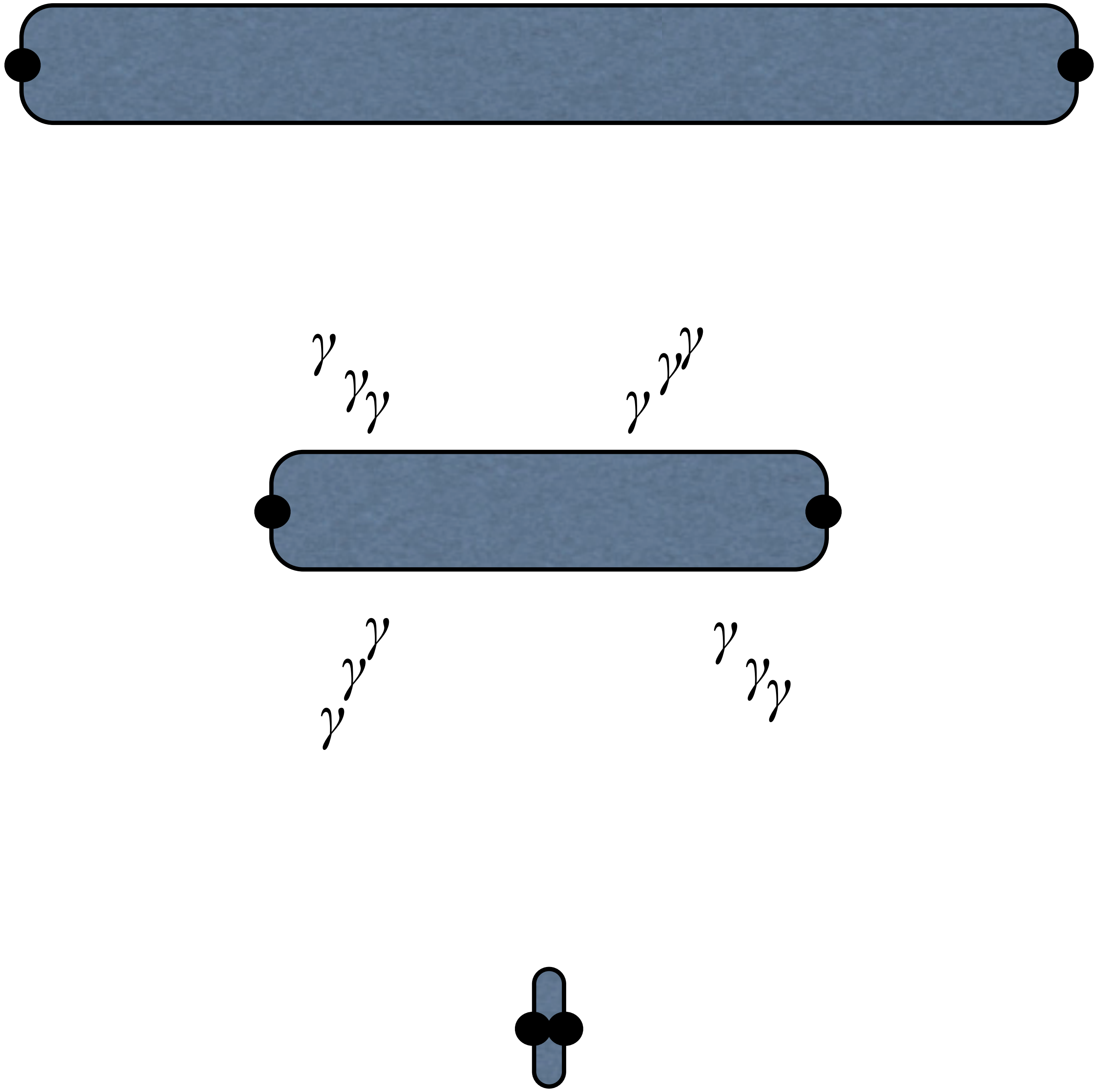
compton wavelength,
$L \sim (m_Q)^{-1}$

$$\Lambda_{IC}^2 > 2m_Q^2$$

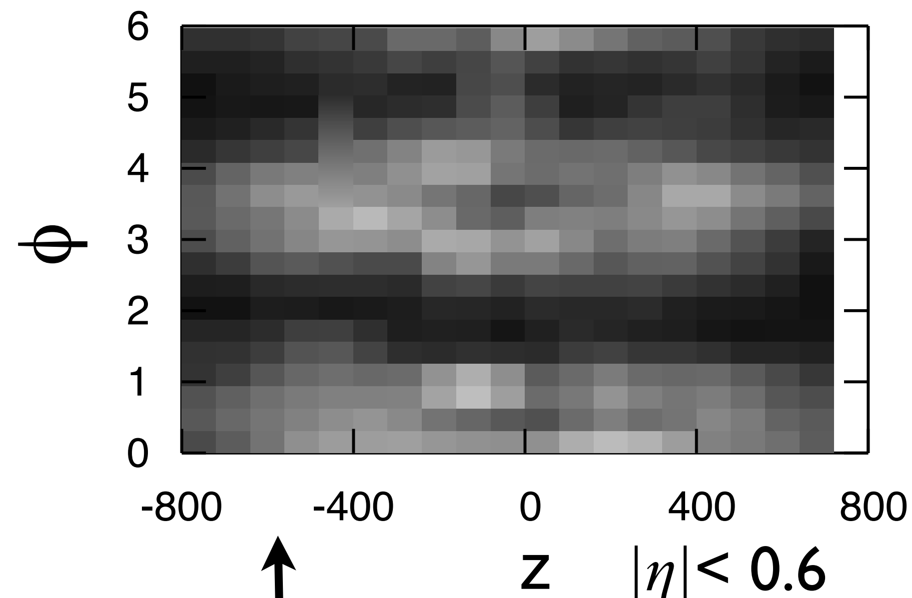
Infra-color strings can't break!

Rich collider phenomenology

Produced in a highly excited state

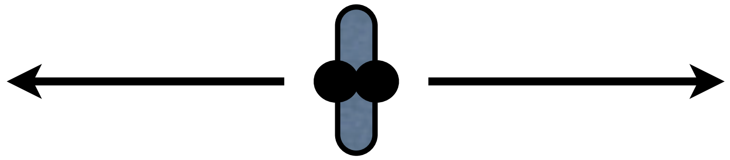


Ground state



R. Harnik, T. Wizansky, Phys. Rev. D80, 075015 (2009)

Very optimistic scenario



Annihilation into
observable high p_T signals

Vectorlike quirkonium annihilation studies

K. Cheung, W. -Y. Keung, T. -C. Yuan, Nucl. Phys. B811, 274-287 (2009)

C. Kilic, T. Okui, JHEP 1004, 128 (2010)

S. P. Martin, Phys. Rev. D83, 035019 (2011)

R. Harnik, G. Kribs, A. Martin, arXiv:1106.2569 (2011)

and so on........

Not many chiral quirkonium decay studies in the market!

Physical motivation for chiral quirks

Quirky baryons can be a **dark matter candidate**

Kribs, Roy, Terning, Zurek, Phys. Rev. D81, 095001 (2010)

Mass degenerate

	$SU(N)_{ic}$	$SU(2)_L$	$U(1)_Y$
Q	$\mathbf{N}$	$\mathbf{2}$	0
u^c	$\bar{\mathbf{N}}$	$\mathbf{1}$	$-1/2$
d^c	$\bar{\mathbf{N}}$	$\mathbf{1}$	$+1/2$

$SU(2)_{ic}$

Yukawa coupling

$$\mathcal{L} = \lambda_U Q H u^c + \lambda_d Q H^\dagger d^c$$

Outline

- Meson states
- Matrix element calculation
- Enhancement factors
- Decay branching ratios

Two quirk flavors, U and D

Neutral quirkonia

$U\bar{U} \quad D\bar{D}$

Charged quirkonia

$U\bar{D} \quad D\bar{U}$

	$SU(N)_{ic}$	$SU(2)_L$	$U(1)_Y$
Q	$\mathbf{N}$	$\mathbf{2}$	0
u^c	$\bar{\mathbf{N}}$	$\mathbf{1}$	$-1/2$
d^c	$\bar{\mathbf{N}}$	$\mathbf{1}$	$+1/2$

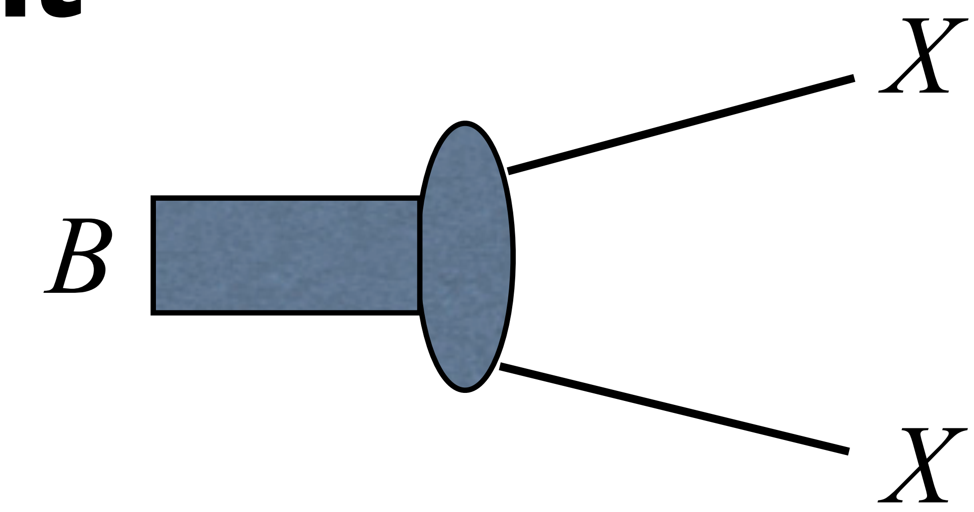
$SU(2)_{ic}$

Lowest lying angular momentum states

	$^{2s+1}l_j$	J^{PC}
$l = 0$	$^1S_0$	0^{-+}
	$^3S_1$	1^{--}
$l = 1$	$^1P_1$	1^{+-}
	$^3P_0$	0^{++}
	$^3P_1$	1^{++}
	$^3P_2$	2^{++}

Decay Matrix Element

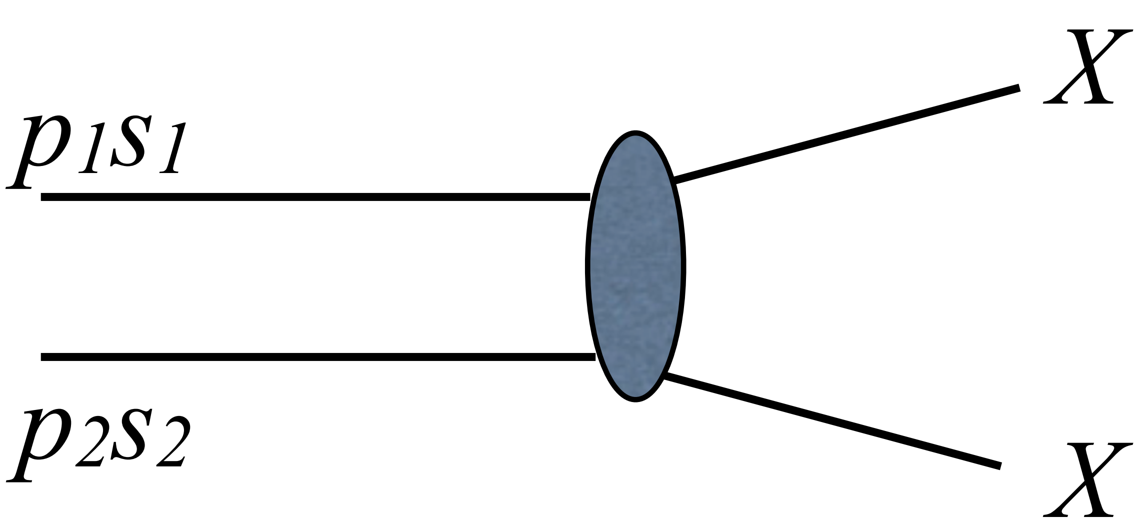
$$iM = \langle X\,X|O|B\rangle$$



Decompose $|B\rangle = |^{2s+1}l_j\rangle$ into $|lmss_z\rangle$

Then $|lmss_z\rangle$ into $|p_1\,p_2;s_1\,s_2\rangle$

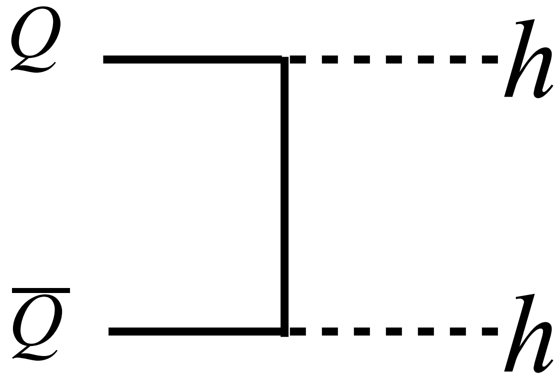
$$iM \sim \langle X\,X|O|p_1\,p_2;s_1\,s_2\rangle$$



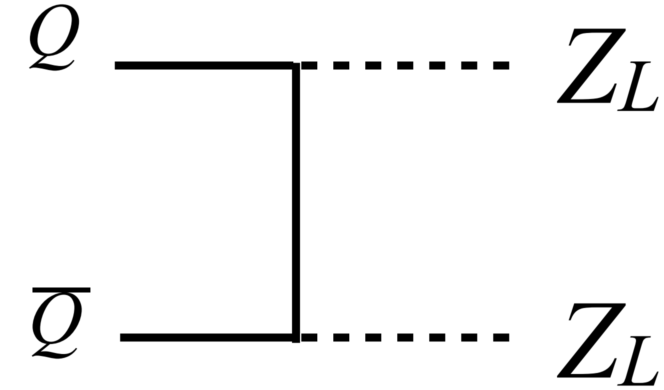
$f\bar{f} \to XX$ matrix element!

B. Guberina, J. H. Kuhn, R. D. Peccei and R. Ruckl, Nucl. Phys. B 174, 317 (1980).

Yukawa and Longitudinal W/Z enhancements

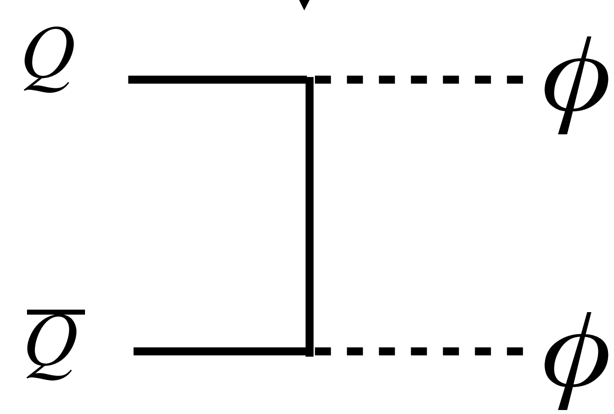


yukawa $\sim m_Q$



$m_Q >> m_Z$

Goldstone equivalence theorem



yukawa $\sim m_Q$

Absent in vector-like quirks!!

Branching Ratios

Parameters

$\Lambda_{IC} \sim O(1\ GeV)$

Kinemetically suppresses IC radiative relaxation from P to S states

$\alpha_{IC} = 0.2$

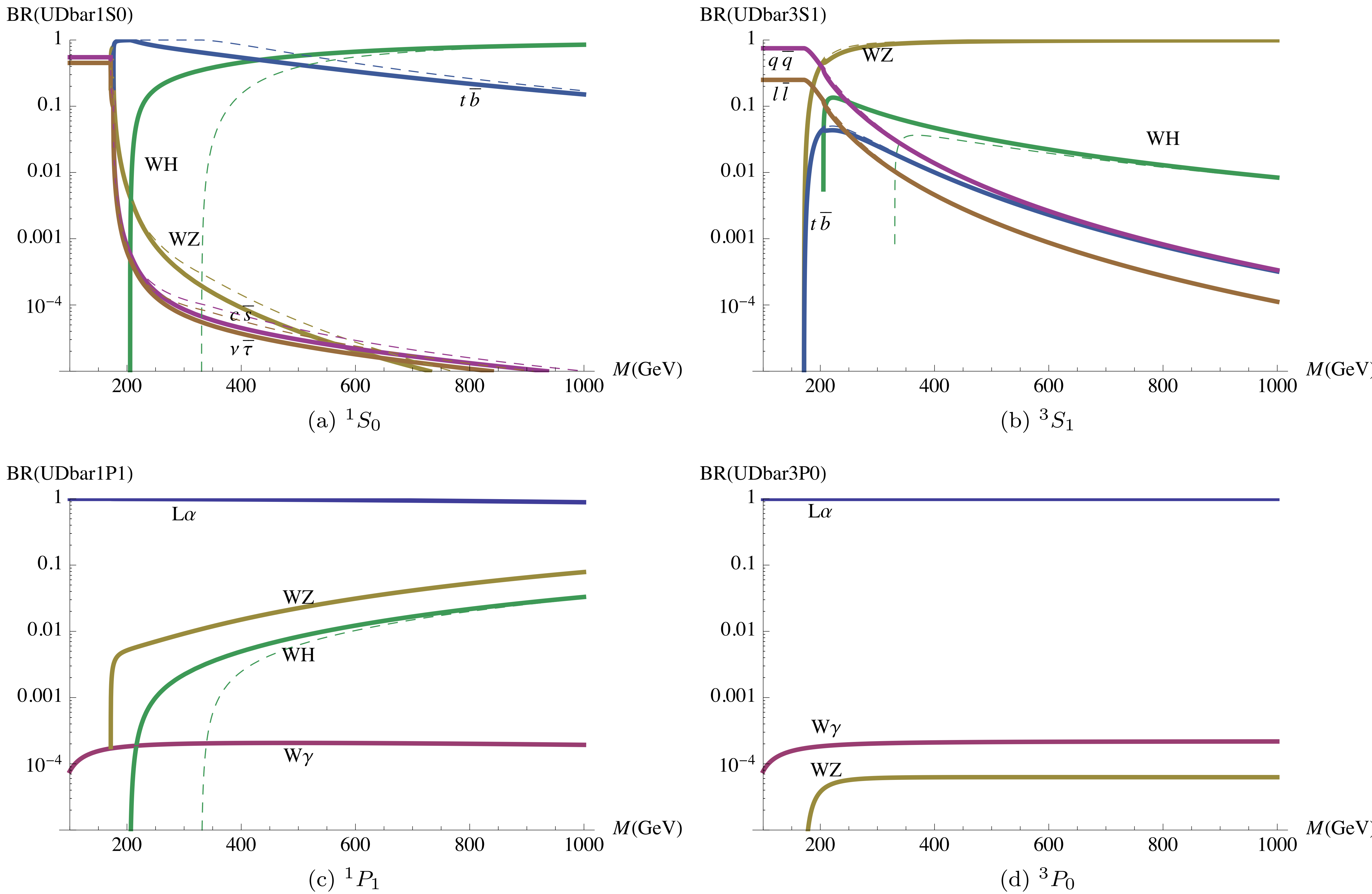
IC is perturbative, Coulomb approx. to wavefunction

For neutral quirkonia, decays into infra-glueballs is Λ_{IC} dependent, calculate width ratios instead for plots

$$WR(Q\bar{Q} \to f) = \frac{\Gamma(Q\bar{Q} \to f)}{\sum_{f \neq \phi' \phi'} \Gamma(Q\bar{Q} \to f)}$$

See our paper for a detailed discussion on how these parameters affect our results.

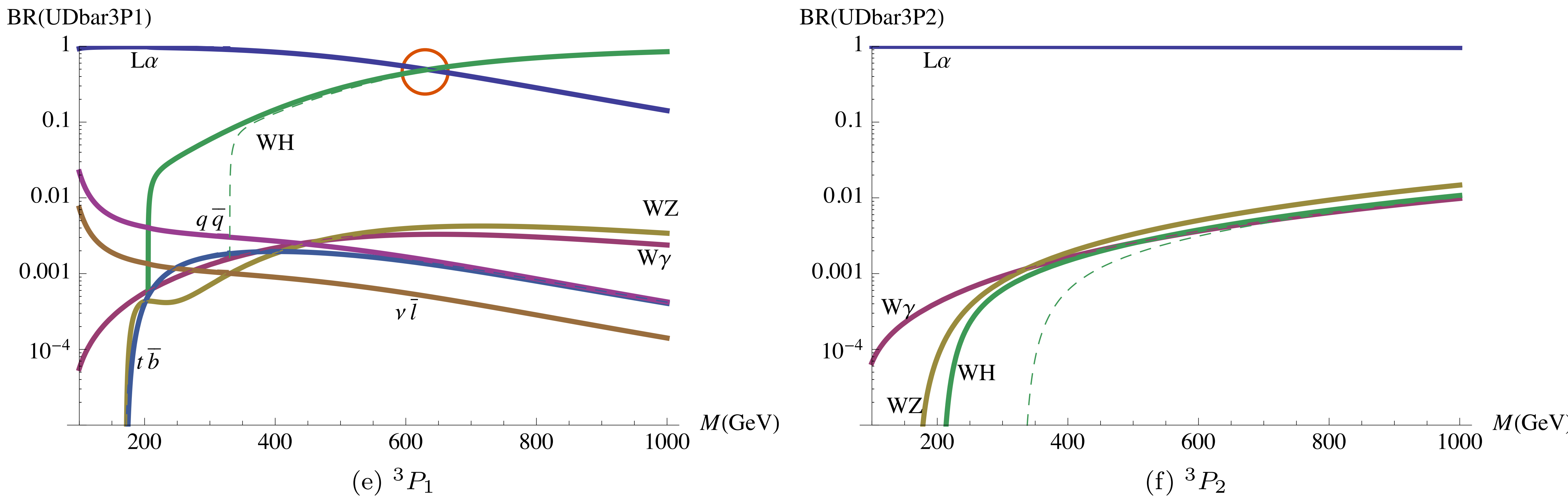
Plots $U\bar{D}$ $U\bar{D}$ Electrically Charged! No glueballs!



(a) $^1S_0$ (b) $^3S_1$ (c) $^1P_1$ (d) $^3P_0$

$m_H = 125, 250\ GeV$ $\alpha_{IC} = 0.2$

Plots $U\bar{D}$ $U\bar{D}$

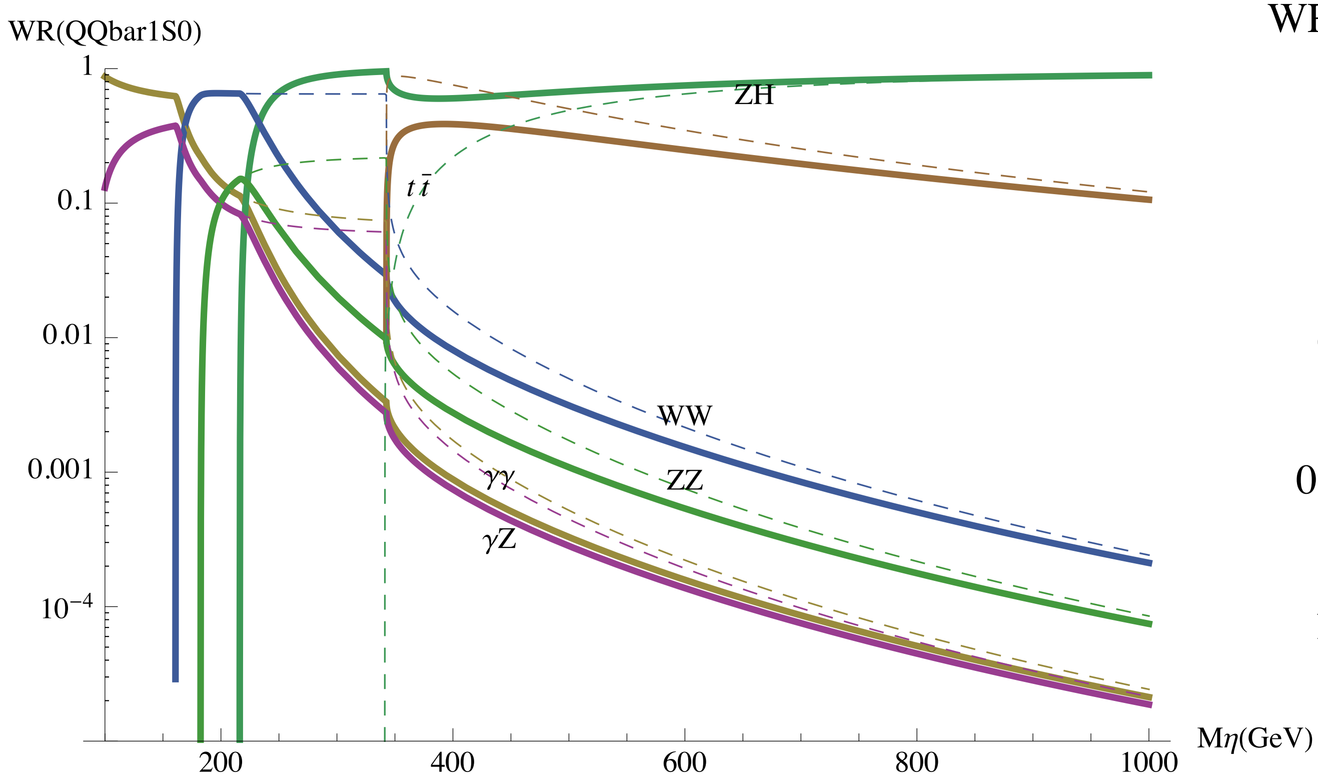


(e) $^3P_1$ (f) $^3P_2$

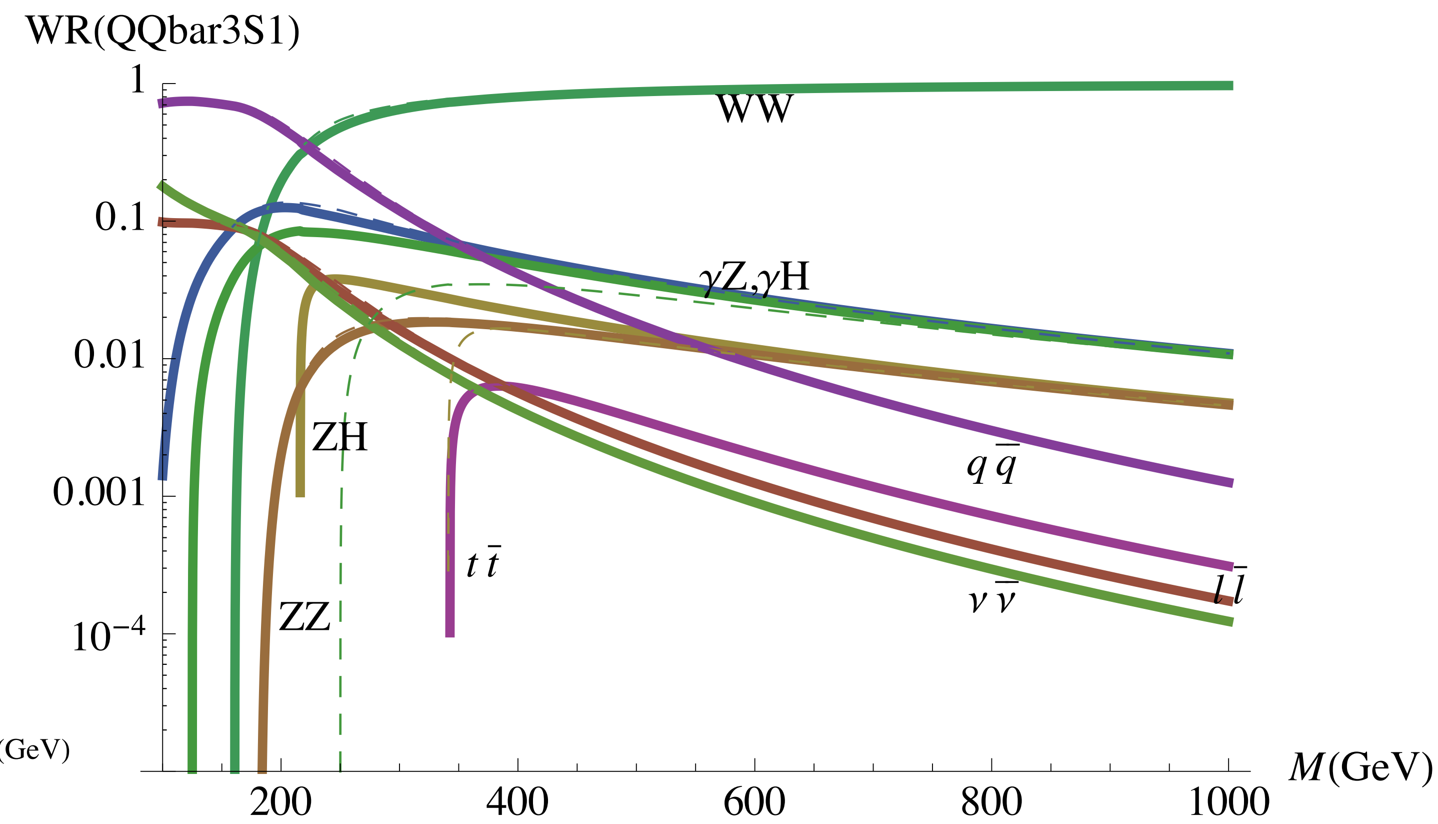
WH dominates over radiative transition at $m_Q > 600\ GeV.$

Doubly enhanced!

Plots $U\bar{U}$ $D\bar{D}$ Electrically neutral



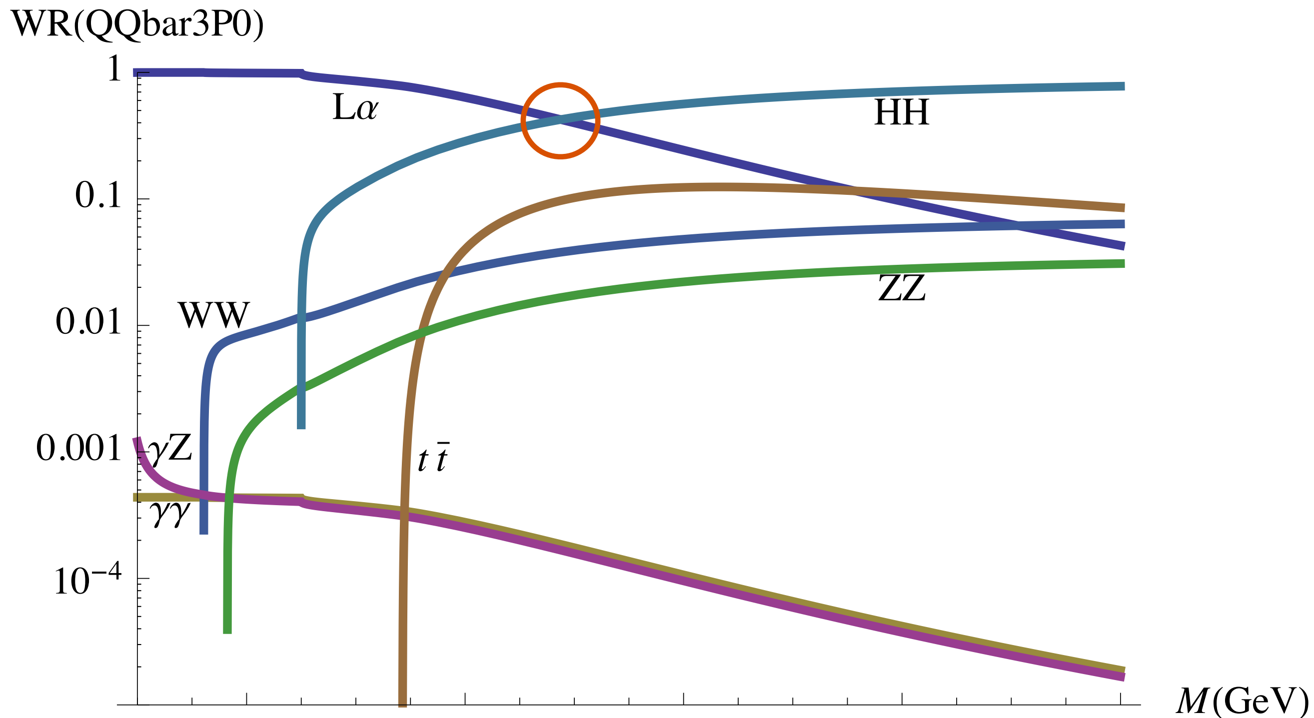
(a) $^1S_0$



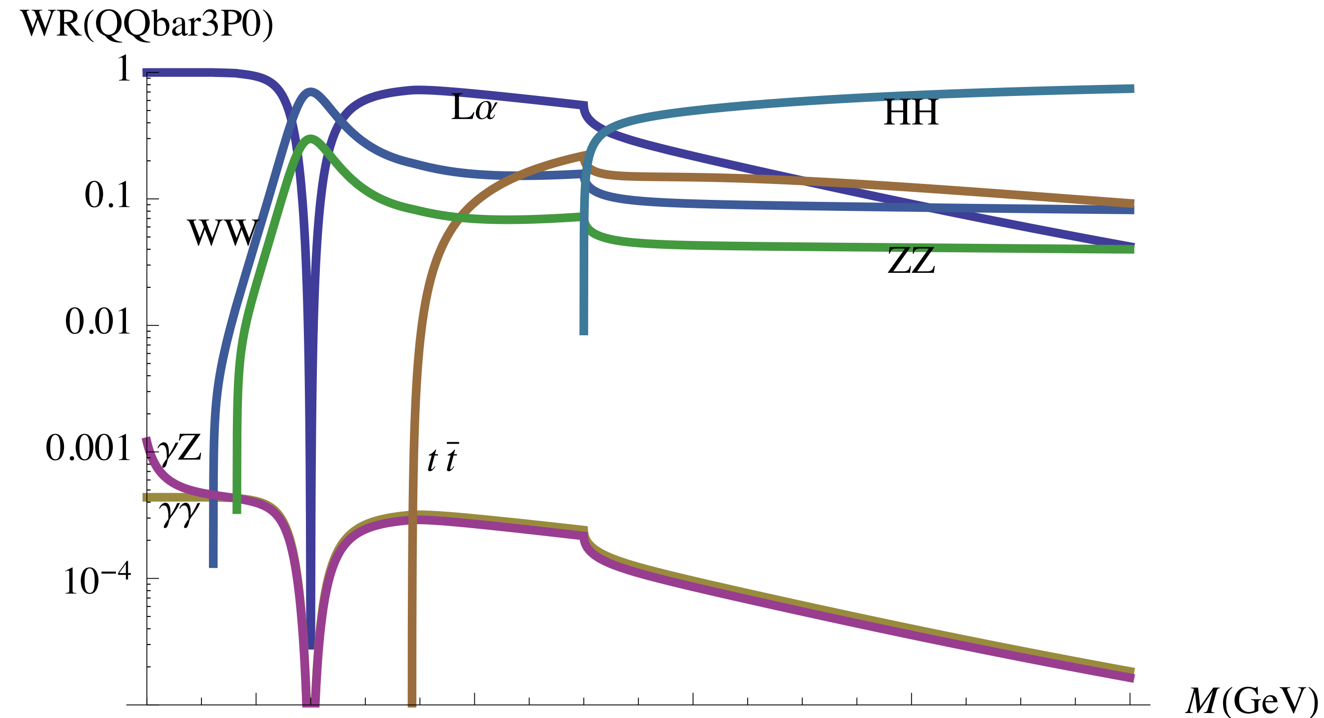
(b) $^3S_1$

Plots $U\bar{U}$ $D\bar{D}$

$^3P_0$

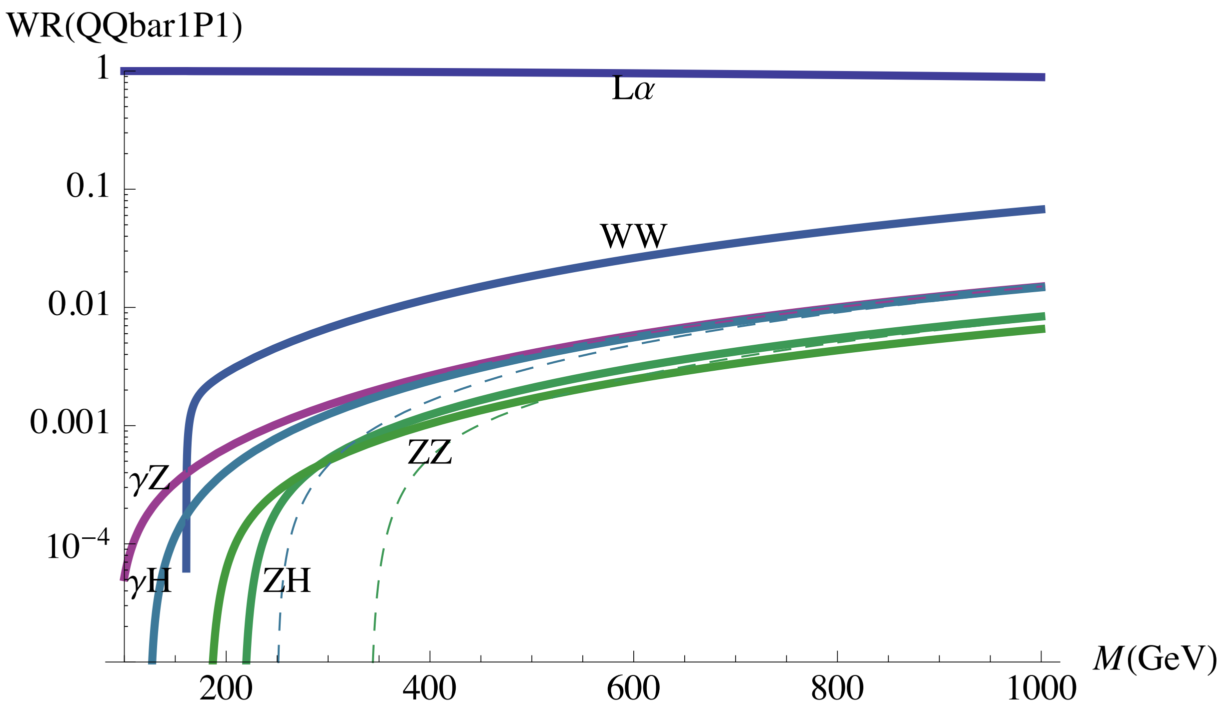


(c) $^3P_0, M_H = 125$ GeV

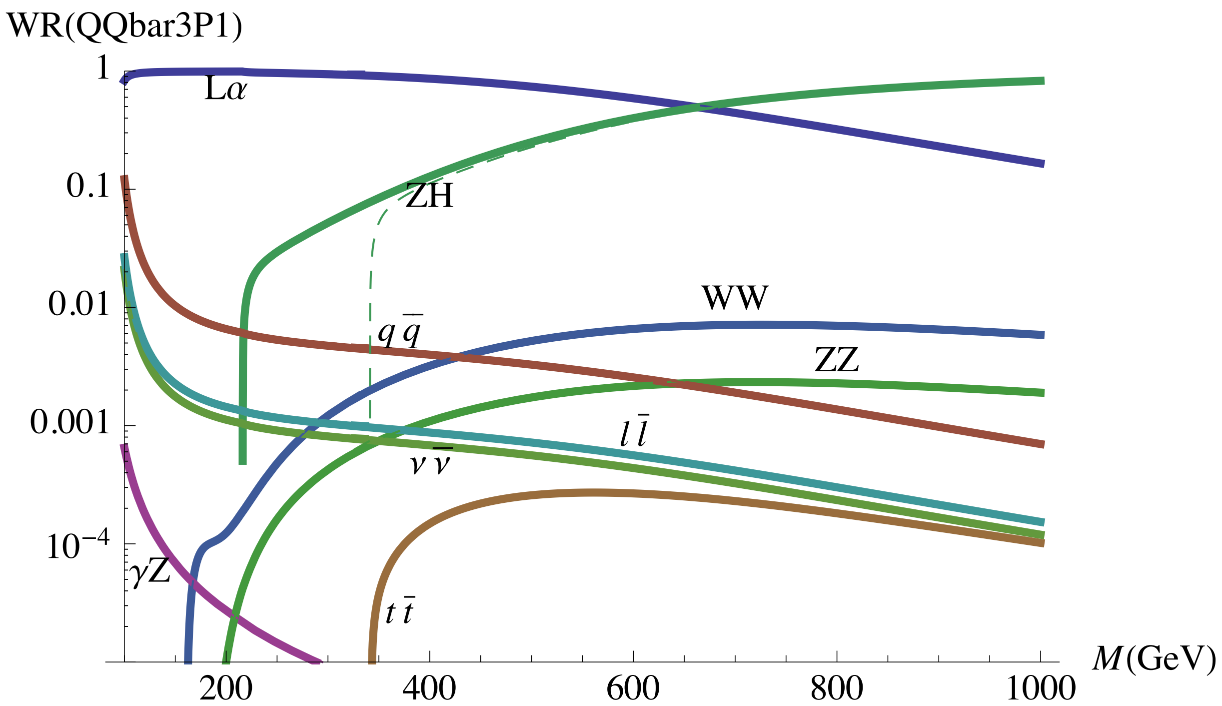


(d) $^3P_0, M_H = 250$ GeV

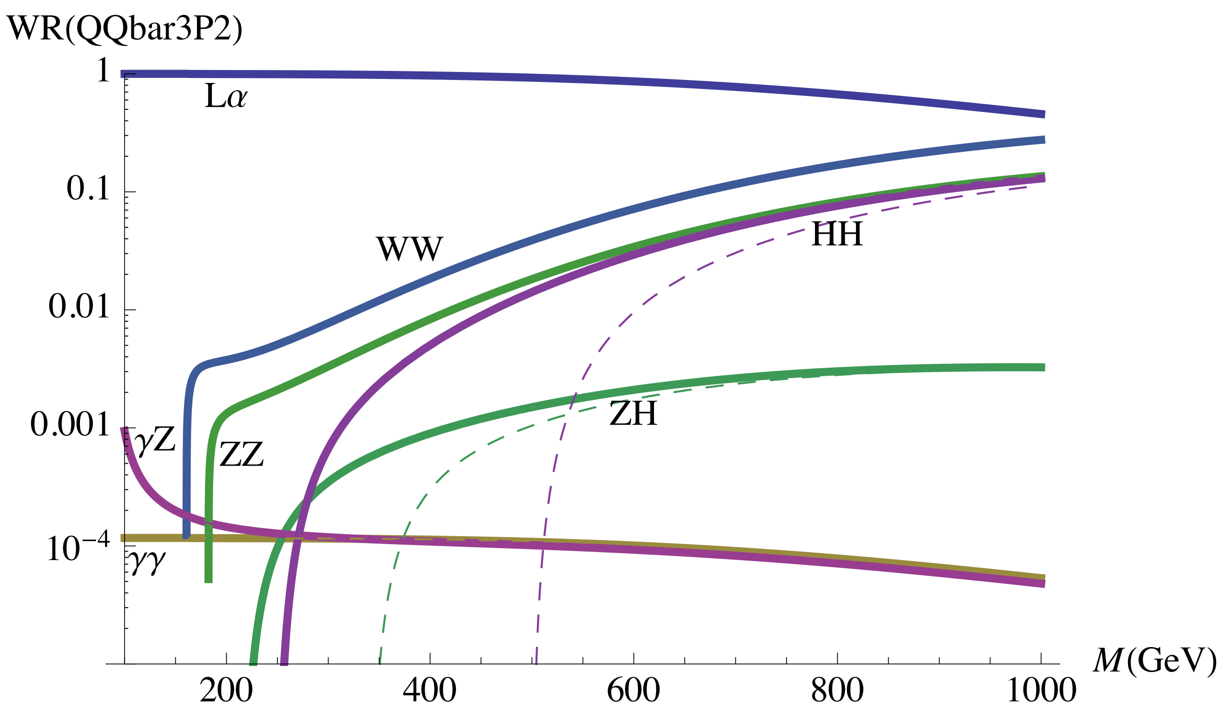
Plots $U\bar{U}$ $D\bar{D}$



(e) $^1P_1$



(f) $^3P_1$



(g) $^3P_2$

Conclusion and outlook

- It is necessary to consider P states for chiral quirks for $m_Q > 500\ GeV$.

- Dominant modes are mostly combinations of *W/Z* and *H*, when kinematically allowed.

- 8 lepton(!!!!) signal from $HH \rightarrow ZZZZ \rightarrow llllllll$ for heavier Higgs masses

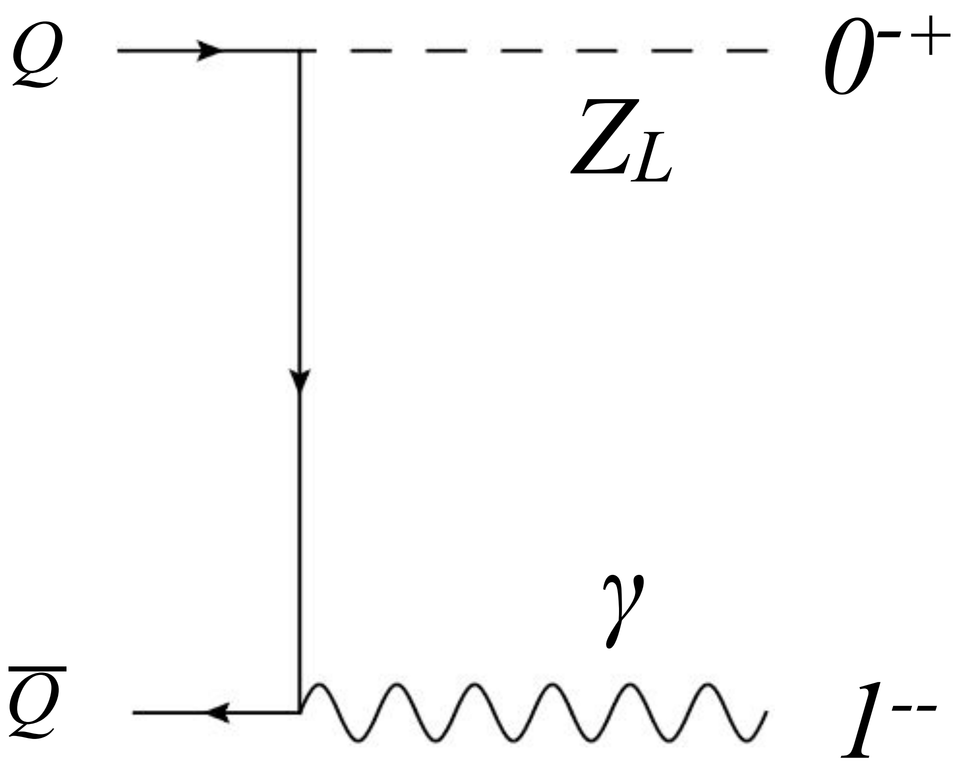
BACKUP SLIDES

Which decay channels are enhanced?

Look at J^{PC} of final states!

e.g. $Z\gamma$

Z_L	0^{-+}
Z_T	1^{--}
γ	1^{--}



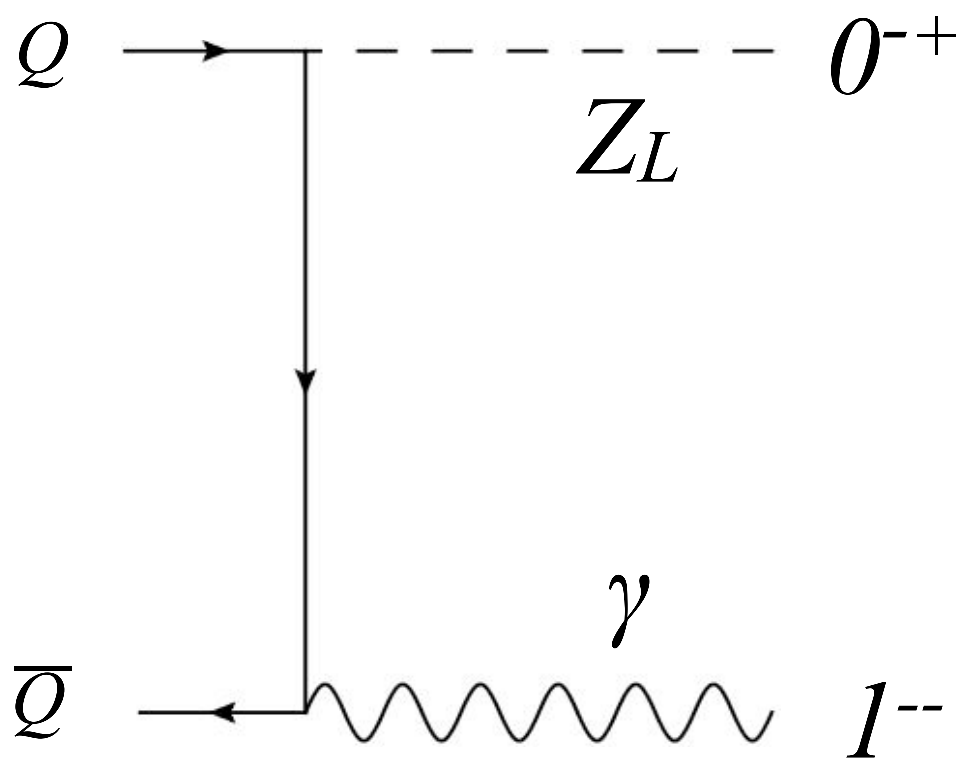
$\boxed{J^{PC} = 1^{+-}}$

Which decay channels are enhanced?

Look at J^{PC} of final states!

e.g. $Z\gamma$

Z_L	0^{-+}
Z_T	1^{--}
γ	1^{--}



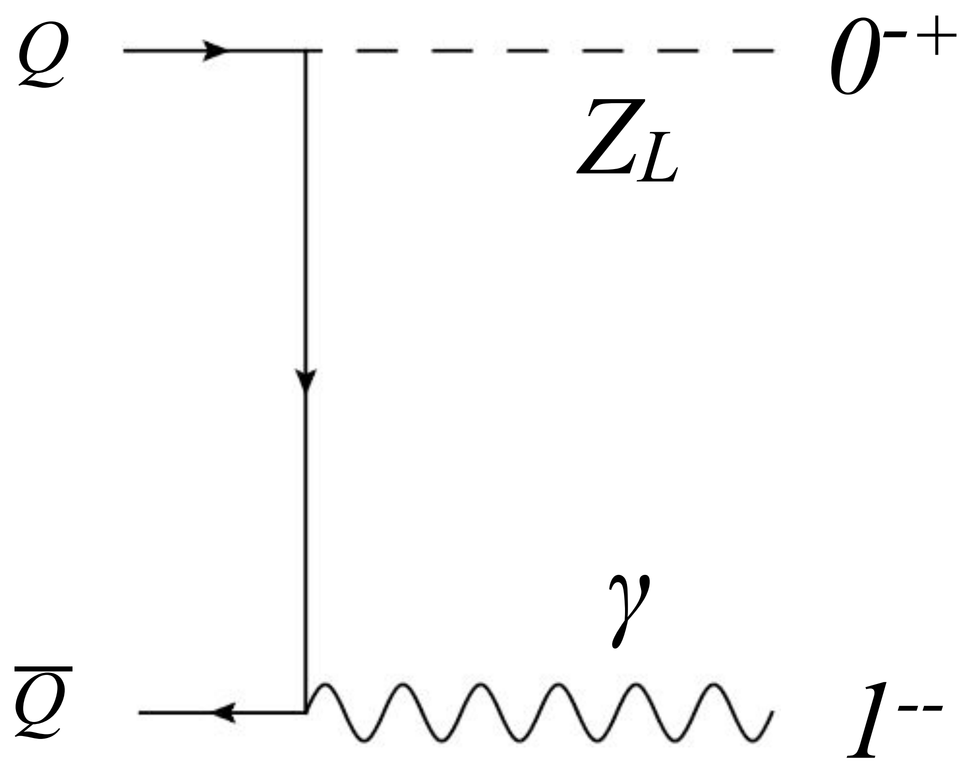
	J=0	J=1	J=2	$L\times S$
L=0		1^{+-}		
L=1	0^{--}	1^{--}	2^{--}	1×1
L=2		1^{+-}	2^{+-}	2×1

Which decay channels are enhanced?

Look at J^{PC} of final states!

e.g. $Z\gamma$

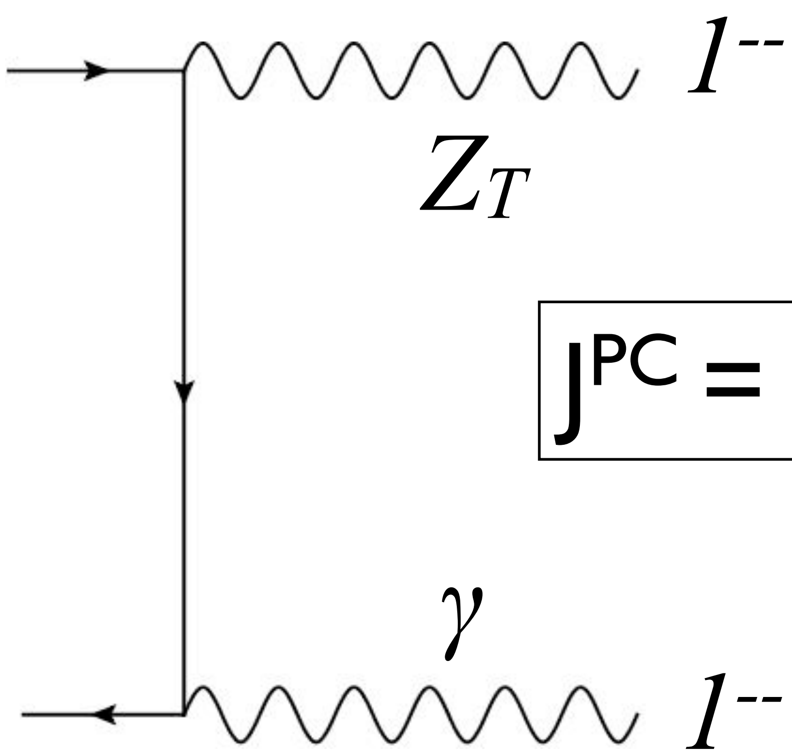
Z_L	0^{-+}
Z_T	1^{--}
γ	1^{--}



	J=0	J=1	J=2	$L \times S$
L=0		1^{+-}		
L=1	0^{--}	1^{--}	2^{--}	1×1
L=2		1^{+-}	2^{+-}	2×1

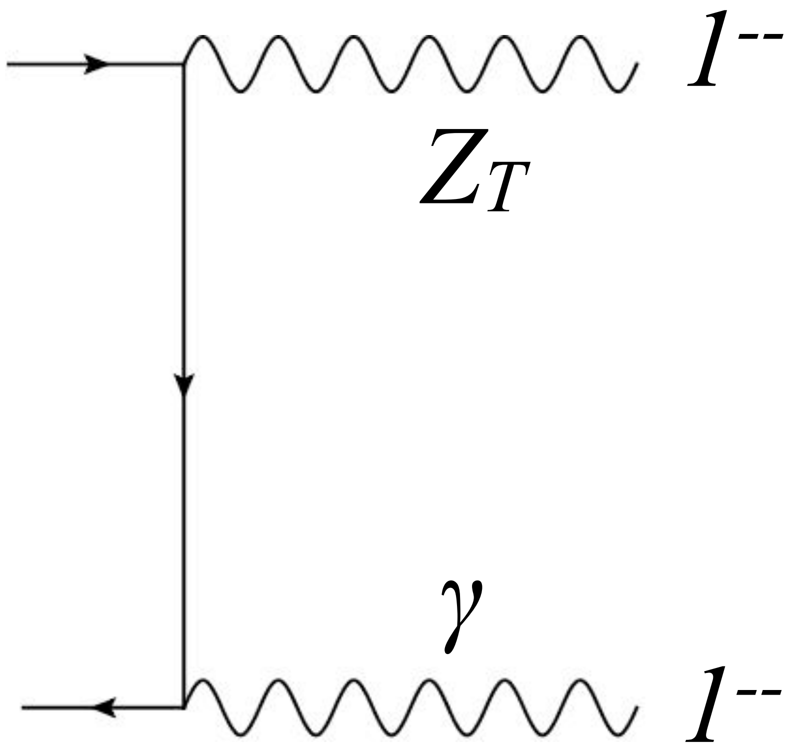
$^3S_1$ $^1P_1$

Works for Z_T too!



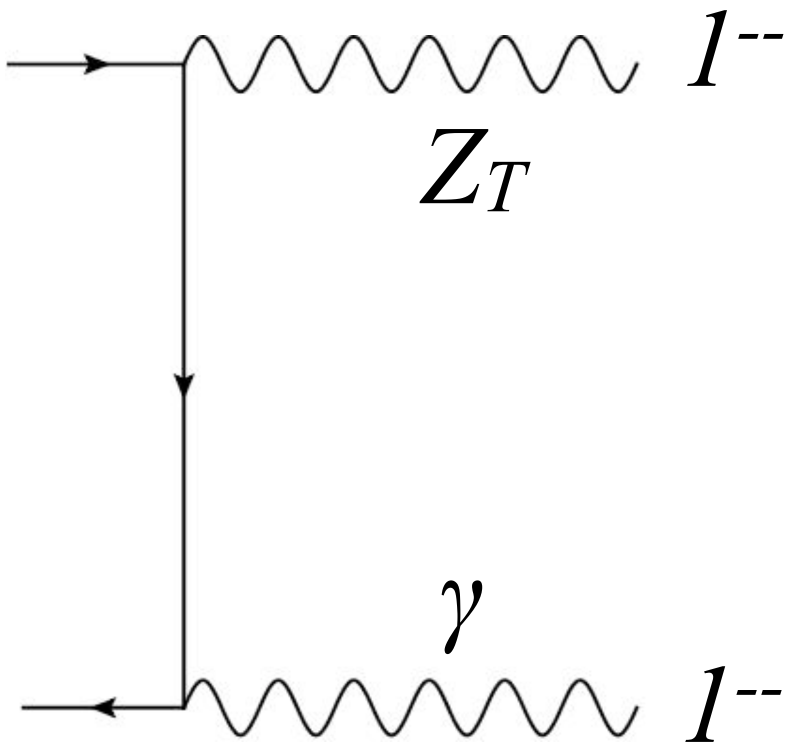
$\boxed{J^{PC} = 0^{++}\ 1^{++}\ 2^{++}}$

Works for Z_T too!



	J=0	J=1	J=2	$L \times S$
L=0	0^{++}	1^{++}	2^{++}	1×1
L=1	0^{-+}	1^{-+}	2^{-+}	
L=2		1^{++}	2^{++}	

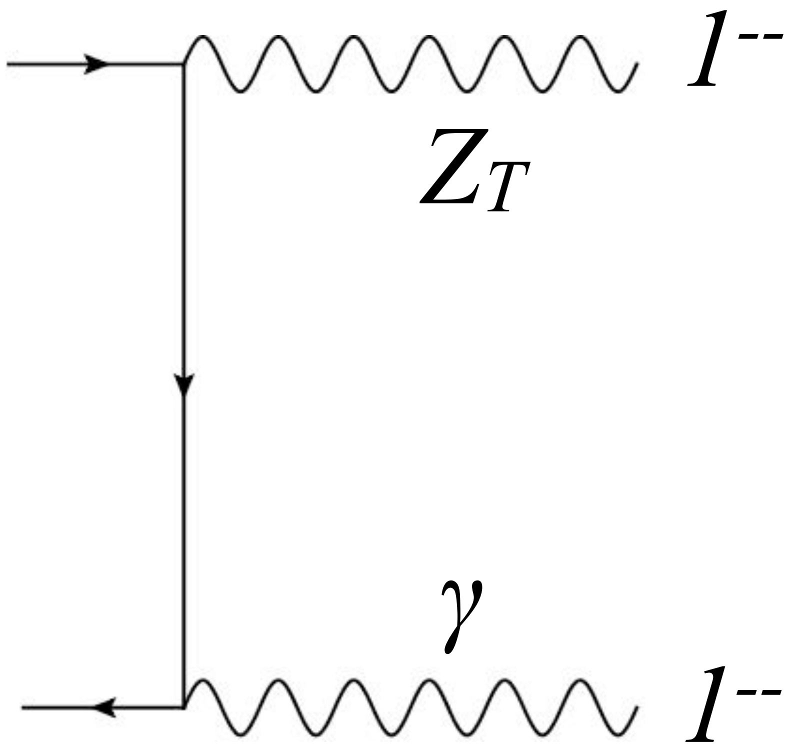
Works for Z_T too!



	J=0	J=1	J=2	$L \times S$
L=0	0^{++}	1^{++}	2^{++}	1×1
L=1	0^{-+}	1^{-+}	2^{-+}	
L=2		1^{++}	2^{++}	

$^1S_0$ $\quad$ $^3P_0$ $\quad$ $^3P_1$ $\quad$ $^3P_2$

Works for Z_T too!



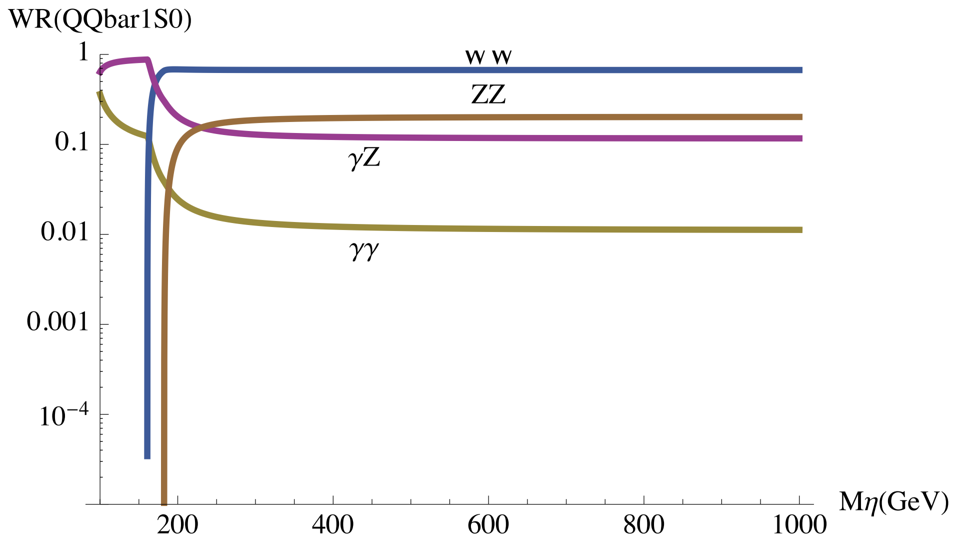
	J=0	J=1	J=2	$L \times S$
L=0	0^{++}	1^{++}	2^{++}	1×1
L=1	0^{-+}	1^{-+}	2^{-+}	
L=2		1^{++}	2^{++}	

$^1S_0$ $\quad$ $^3P_0$ $\quad$ $^3P_1$ $\quad$ $^3P_2$

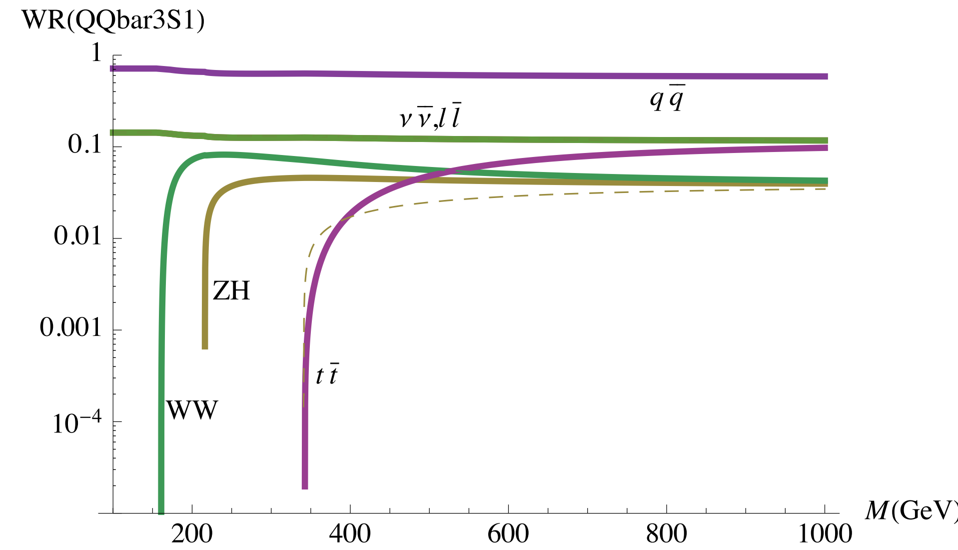
Enhanced $\quad$ $^3S_1$ $\quad$ $^1P_1$

~~Enhanced~~ $\quad$ $^1S_0$ $\quad$ $^3P_0$ $\quad$ $^3P_1$ $\quad$ $^3P_2$

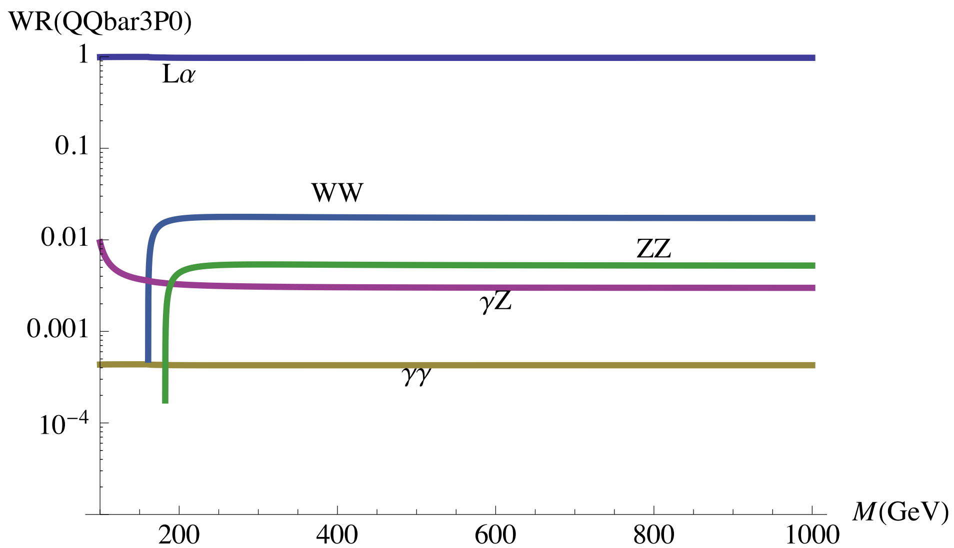
Vector-like quirkonium decays



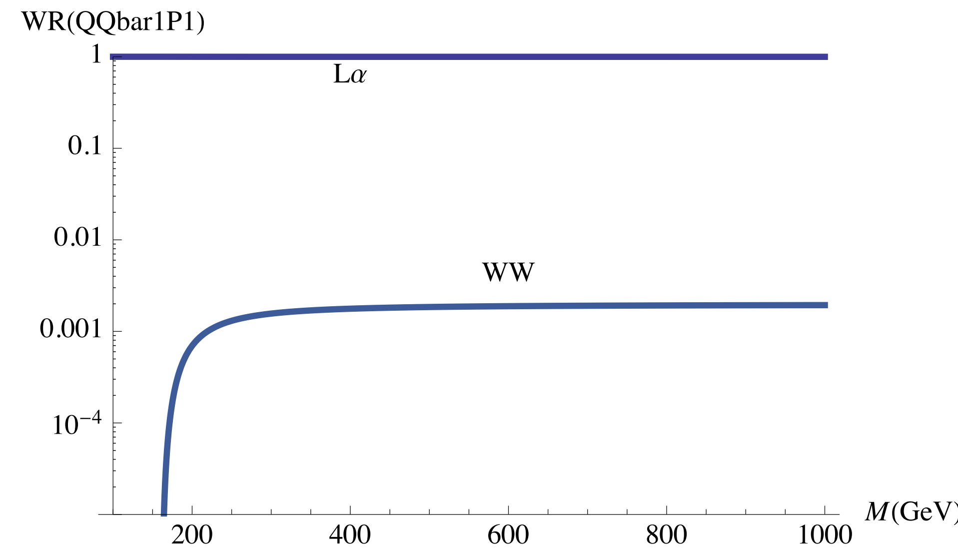
(a) $^1S_0$



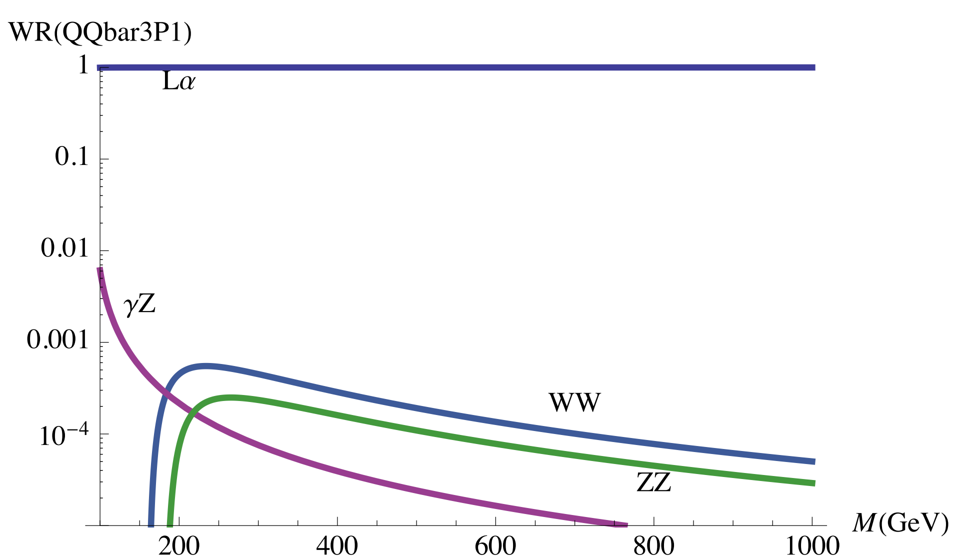
(b) $^3S_1$



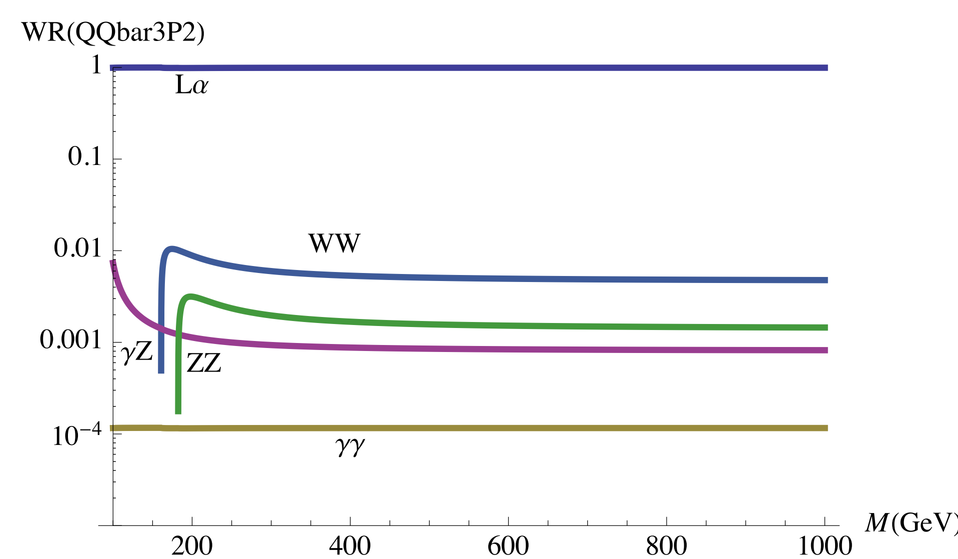
(c) $^3P_0, M_H = 125$ GeV



(d) $^1P_1$

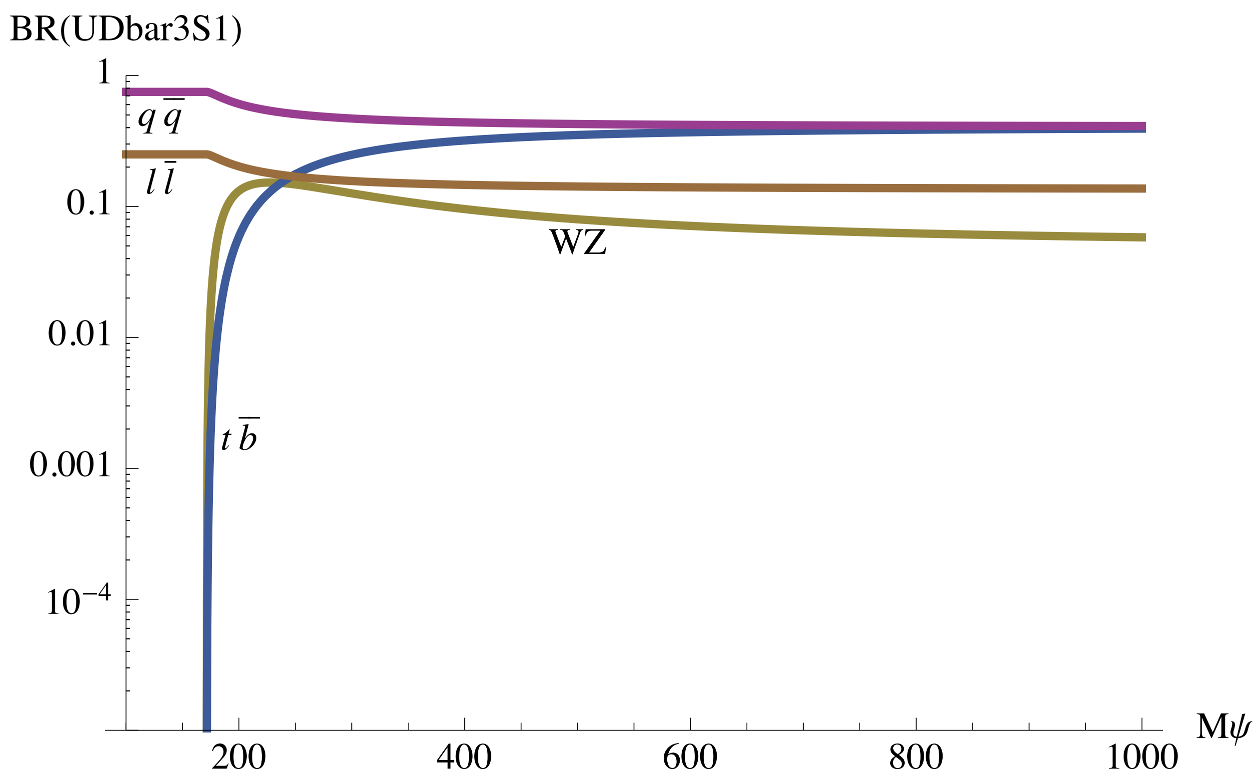


(e) $^3P_1$

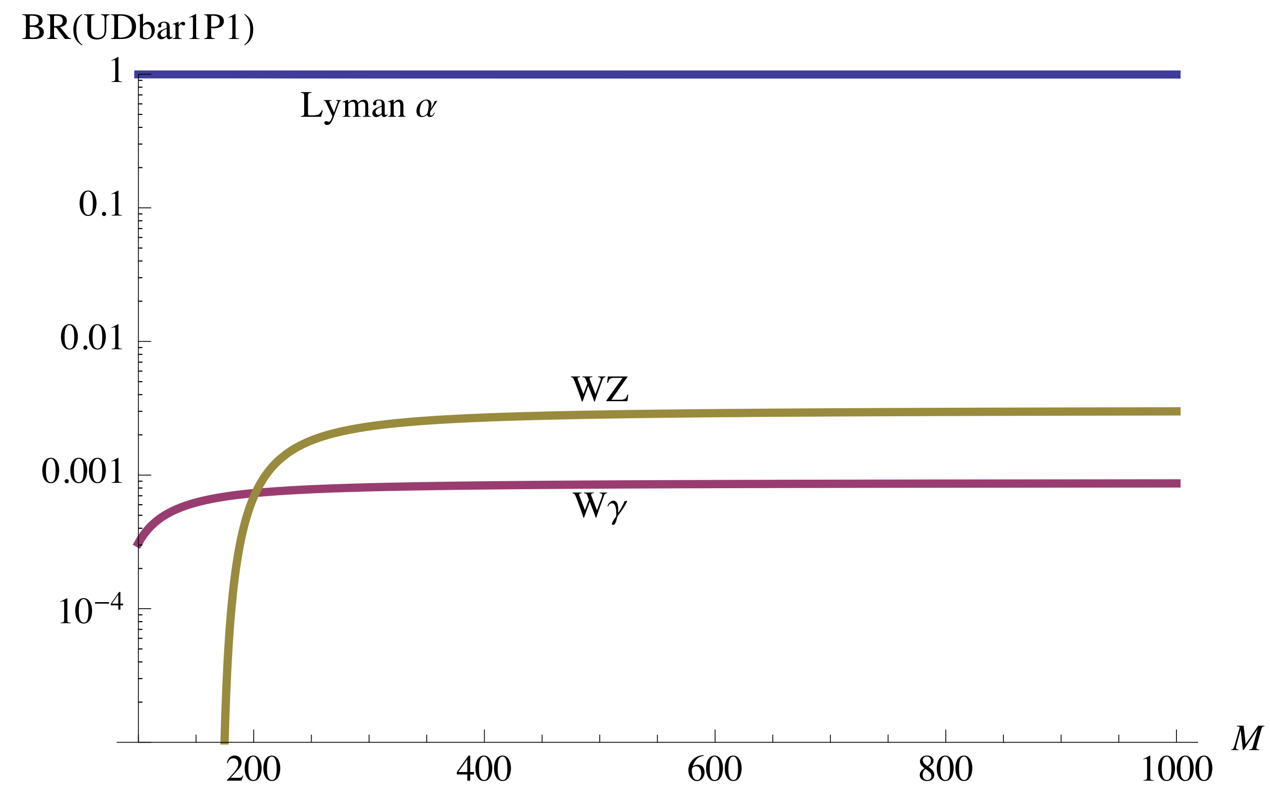


(f) $^3P_2$

Vector-like quirkonium decays

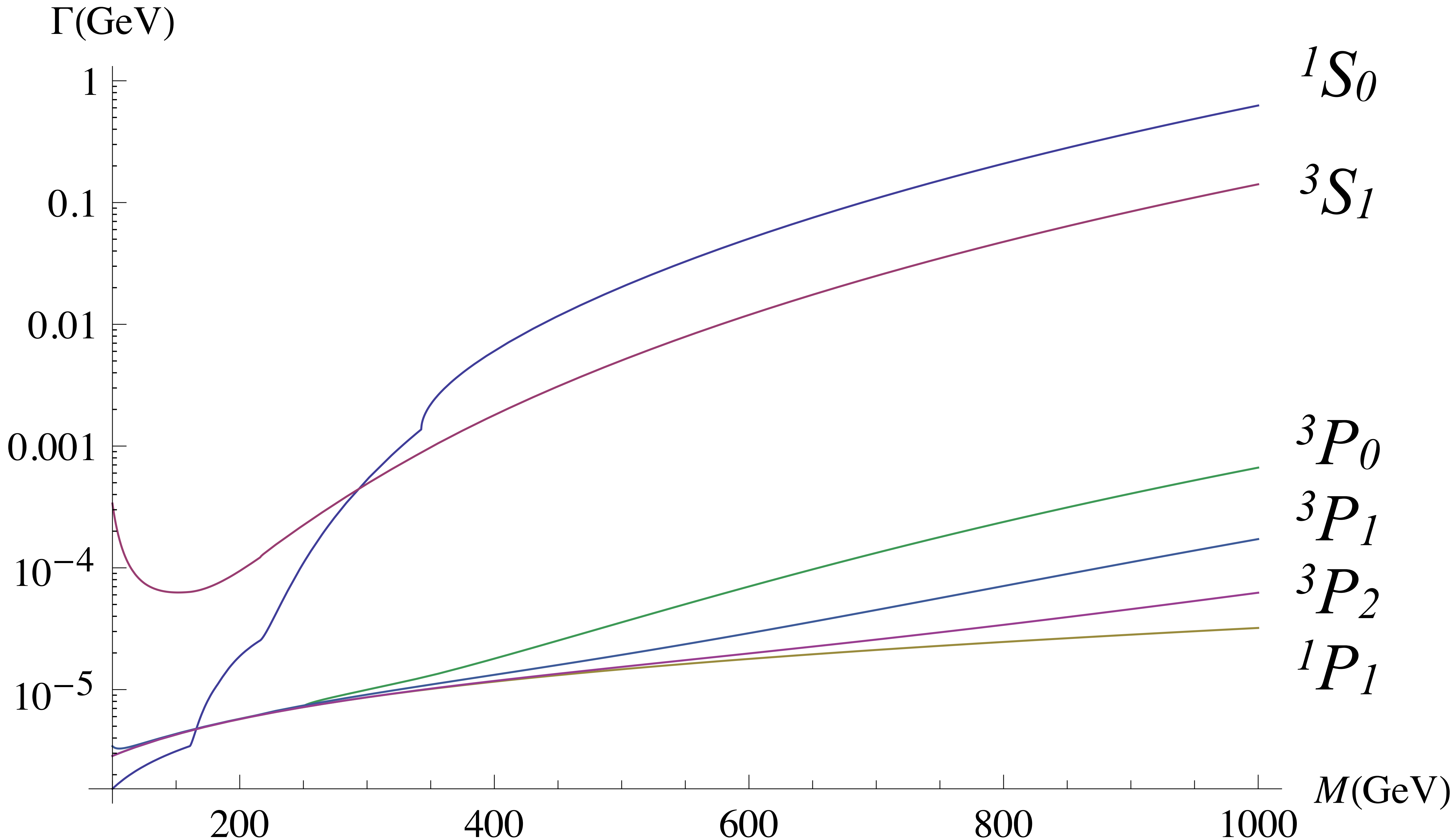


(a) $^3S_1$



(b) $^1P_1$

$U\bar{U} \quad D\bar{D}$



$$
\begin{aligned}
|B\rangle = |{}^{2s+1}l_j\rangle &= \sum_{MS_z} \langle lmss_z|jj_z\rangle |lmss_z\rangle \\
&= \sqrt{\frac{2}{M}} \int \frac{d^3\mathbf{q}}{(2\pi)^3} \psi^{lm}(\mathbf{q}) \left[\sum_{ms_z} \langle lmss_z|jj_z\rangle \right] \\
&\quad \left[\sum_{s_1 s_2} \langle s_1, \frac{1}{2}, s_2, \frac{1}{2}|ss_z\rangle \right] |s_1 p_1 s_2 p_2\rangle,
\end{aligned}
$$